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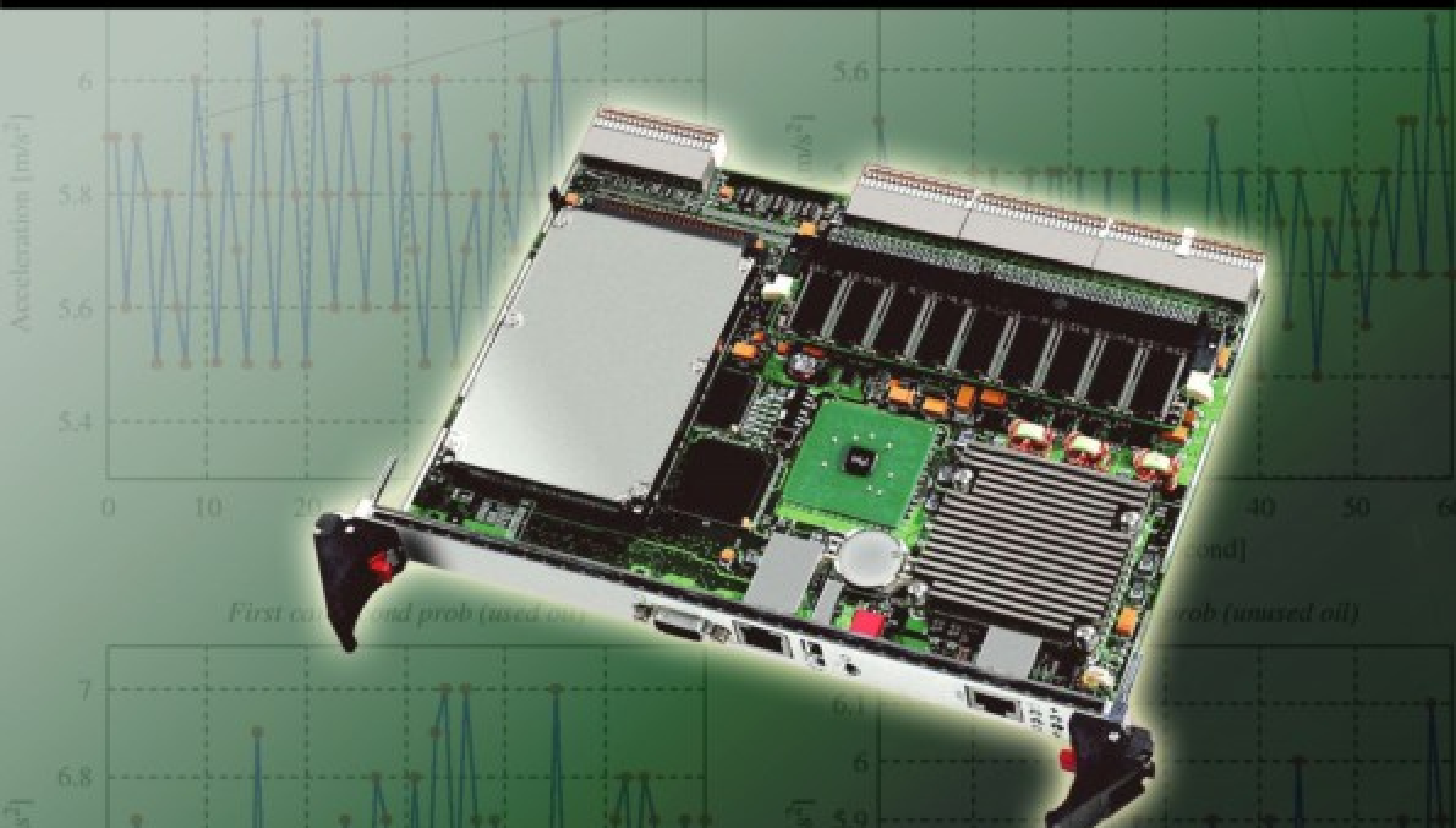

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Adaptive Fuzzy Control of Aircraft ABS Based on Runway Identification

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Abstract: Modern civil aircraft requires all-weather frequent landing on permissive runway surface conditions as well as better braking performance. In order to meet such requirements, this paper starts with the kinematics of aircraft Anti-skid Braking System (ABS) ,and analyses the mathematical models of wheels, tyres and runway, hydraulic servo valves, brakes, etc. The runway identification is established based on Magic Formula, the desired slip ratio is real-time adjusted according to the runway surface condition. On this basis, the fuzzy control with input variables of the slip ratio error and its change ratio is introduced. Simulation and dynamometer tests show that this system has the satisfying braking effect in different runway status. The adaptability and robustness are greatly enhanced and improved, which ensure the successful development of aircraft ABS in integrated environment. *Copyright © 2012 IFSA.*

Keywords: Fuzzy control, Runway identification, Slip-ratio, Simulation, Dynamometer test.

1. Introduction

The aircraft ABS plays an important role in aircraft taking off, landing, taxiing and steering. During the landing braking process, effected by the speed, runway status (dry, wet, ice, etc.), crosswind, the aircraft ABS is nonlinear, time-varying and uncertain. It is difficult to establish its precise mathematical model [1-3]. With the development of intelligent technology, the fuzzy control has gradually been applied in the braking systems of automotive and aircraft because of the features of strong robustness and imprecise reasoning [2-8]. But these applications mainly focus on the control law improvement, and automatic identification of the runway status isn't studied in depth. When the runway status changes, the braking efficiency is not high, the braking distance is longer.

Overrun accidents in recent years mostly occurred on wet runway or water runway [1, 9-11], therefore, to take advantage of the maximum friction of the pavement, and ensure the safety of aircraft braking, the effective recognition of the runway status is very necessary, especially for civil aircraft.

In this paper, the relevant mathematical models of aircraft braking systems are introduced, and a fuzzy brake control system based on the identification of the runway status is designed. Simulation and dynamometer tests results show that the robustness, anti-interference ability and adaptability of the runway status are enhanced. The safety and reliability of the aircraft braking system are improved.

2. Mathematical Models

The friction force between tyres and ground is master factor during landing braking, but it is non-linear with the different of speed and runway status. The purpose of aircraft ABS is to prevent the wheels from locking, avoid tyre excessive wear or blasting, and take advantage of the maximum friction of the pavement to achieve smooth and efficient braking. The common Aircraft ABS is composed of the braking instruction sensor, the Anti-skid Braking Control Unit (ABCU), tachometers, pressure servo valves and the wheels (with brakes and tyres), see Fig. 1.

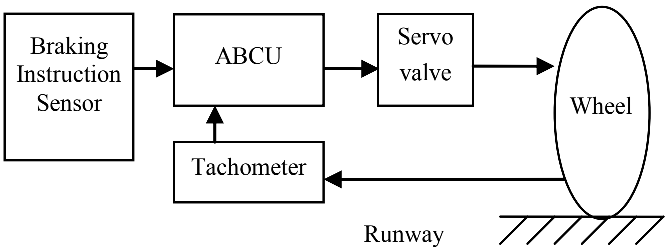


Fig. 1. Structure of Aircraft ABS.

For convenience of study, it is assumed that the aircraft the symmetry landing and tyre deformation is small, and ignore the wheels rolling friction and side winds. The ABS is simplified into a single wheel system. This system includes wheel model, runway and tyre model (see next Chapter), the hydraulic servo valve model and the brake model.

2.1. Wheel Model

In the research process, influence of tyre rolling resistance and air resistance are ignored, the wheel forces of single wheel during landing are shown in Fig. 2. The kinetic equation as follows:

$$\begin{aligned} &M \cdot a = F_t = n \cdot F_m \\ &J \cdot \beta = F_m \cdot R_g - M_{brk} \\ &F_m = \mu \cdot F_z \\ &\sigma = (V - \omega \cdot R_g)/V \end{aligned} , \tag{1}$$

where: M is the aircraft mass, F_t is the aircraft braking total force, n is the number of the braked wheels, V is the aircraft speed or reference speed, α is the aircraft acceleration, J is the wheel moment of inertia, ω is the angular velocity of wheel, β is the angular acceleration. M_{brk} is the wheel braking torque, R_g is the tyre rolling radius, F_z is the vertical reaction force.

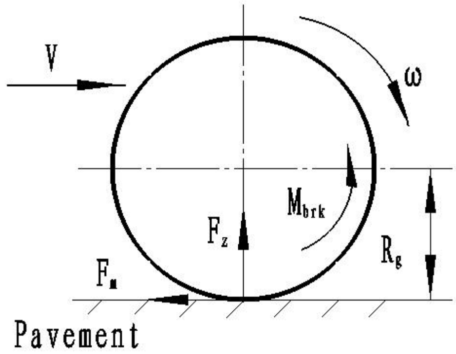


Fig. 2. Forces acting on a braked wheel.

2.2. Hydraulic Servo Valve Model

To achieve brake control, the servo valve control current is regulated to change the braking pressure. Based on the actual experiments, the dynamic characteristics of the hydraulic servo system are determined by the electro-hydraulic pressure servo valve. So, the hydraulic servo system is considered as a Second-order Oscillating Link as following:

$$G(s) = \frac{k_v \cdot \omega_n^2}{S^2 + 2\xi \cdot \omega_n \cdot S + \omega_n^2}, \tag{2}$$

where k_v is the Gain; ω_n is the natural frequency of the servo valve, and ξ is the damp of servo valve.

2.3. Brakes Model

The Brakes which installed in the wheel hub cavity, is composed of the cylinder seat, rotor disk, stator disk and so on. It can transform the braking pressure into the braking torque. When braking, the pressure is applied from servo valve to impacted disk, for squeezing each other, the friction torque between the static and rotor disk is generated, which leads to the kinetic energy is converted into heat energy released. The braking torque is closely related to the braking thrust, the friction properties of the material, the number of friction surfaces and so on.

$$M_{brk} = \mu_{mc} \cdot N_{mc} \cdot S_t \cdot (D_s + d_s)/4, \tag{3}$$

where: N_{mc} is the number of friction surfaces, μ_{mc} is the friction coefficient, S_t is the axial force acting on brakes, D_s is the brake disk outside diameter, d_s is the brake disk inside diameter.

3. Runway Identification

3.1. Braking Action

According to the rules of International Civil Aeronautics Organization (ICAO), the runway surface condition is classified as dry, damp, wet, water patches, ice and so on. With the different runway status, the friction coefficients of runway are different, which results that the braking effect also different. Table 1 show the braking action on different runway status [9].

Table 1. Braking effect.

Airplane Braking coefficient	Pilot-reported braking action	Runway description
0.4	–	Approximate dry runway friction certification values
0.2	Good	Wet runway
0.1	Fair/Medium	Ice
0.05	Poor/Nil	Wet Ice/Melting Compacted Snow

3.2. Tyre Model and Runway Identification

In the case of certain load, the friction coefficient influenced by many factors such as aircraft speed, slip-ratio, the vertical load, the tyre condition, the runway surface condition, etc. Among them, the slip-rate and runway surface condition are most complex with the largest effect. Fig. 3 shows a typical relation between the friction coefficient μ and the slip-ratio σ on diverse runway.

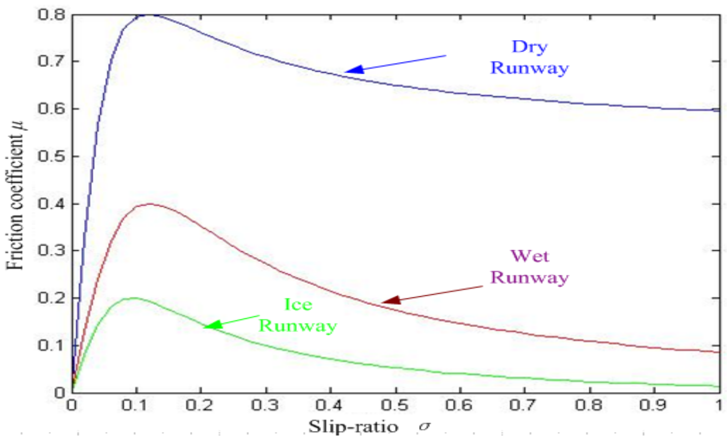


Fig. 3. Friction coefficient μ vs. slip-ratio σ.

Currently, the model based on the Magic Formula is widely used to express the model of the tyre and runway. The Magic Formula is firstly introduced by Pacejak professor [12]. The tyres models of the longitudinal force, lateral force and aligning torque, are expressed with the same trigonometric formula [12-13], such as equation (4).

$$\begin{cases} Y = D \cdot \sin(C \cdot \arctan(B \cdot \varphi)) + S_v \\ \varphi = (1 - E)(X + S_h) + (E / B)\arctan(B(X + S_h)) \end{cases}, \tag{4}$$

where: Y is the longitudinal force or lateral force or aligning torque, D is peak factor indicating the maximum of the curve, B is the stiffness factor, E is the curvature factor indicating the shape of the curve maximum value near, C is the curve shape factor, S_h is the horizontal direction drift of curve, S_v is the vertical direction drift of curve, X is longitudinal slip-ratio σ or the lateral deflection angle under action of lateral force and aligning torque.

To reduce the amount of computation, according to the characteristics of the braking system and the assumption of single-wheel system, the simplified magic formula [5, 14], as equation (5), is used as the model of the longitudinal friction coefficient and slip ratio between the tyre and the runway.

$$\mu = D \cdot \sin(C \cdot \arctan(B \cdot \sigma)), \quad (5)$$

To identify the runway, aircraft deceleration rate and the slip-rate change are compared with the pre-stored data of runway status, to judge which condition the runway (dry, wet, ice, etc.) is, the best expected deceleration rate is real-time adjusted based on the current runway status, and the fuzzy controller outputs the corresponding braking pressure.

On the basis of the equation (5), according to a large number of actual runway friction coefficient [1, 9] and the test data of dynamometer and flight, research results show that the friction coefficient is approximate 0.4 on a dry runway, the friction coefficient is generally more than 0.2 on the wet runway, the friction coefficient is generally above 0.1 on ice runway allowing landing, when the runway friction coefficient below 0.1, it is prohibited for landing, that is not considered here.

Some parameters used in paper, such as σ_r, B, C, D are as follows.

Dry runway (0.16, 10.0326, 1.5344, 0.8);
Wet runway (0.12, 8.2098, 2.0192, 0.4);
Ice runway (0.08, 12.2198, 2.0875, 0.18).

4. The Adaptive Fuzzy Controller

The fuzzy control is an intelligent control method to dynamic control system abided by certain rules combined with practical experience, which fuzzy inference method is similar to the human brain. The concept of fuzzy sets first proposed in 1965 by the famous American cybernetics expert L.A. Zadeh.

The fuzzy controller is the core of the fuzzy control system. The fuzzy controller is made up of input variables, fuzzification, fuzzy inference, defuzzification judgment and output variables and so on. Fig. 4 shows the schematic of the adaptive fuzzy control system based on runway identification.

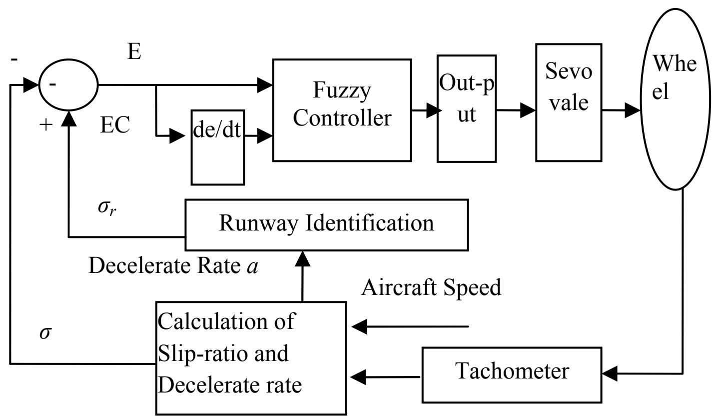


Fig. 4. Schematic of fuzzy control.

4.1. Variable and Fuzzification

According to the ABS operating principle and FIG 3, the optimum slip-ratio value varies from 5 % to 18 % [15], therefore, the desire slip-ratio σ_r is crucial for this system. The slip-ratio error and its change rate are chosen as input variables, the braking pressure is chosen as the output variable. Slip-ratio error is defined as the difference of the real-time slip-ratio and the desire slip-ratio, $E=\sigma_r-\sigma$, the error change rate $EC = de/dt$, the braking pressure variable is U. The domains of E, EC, U, are respectively set to [-2 2], [-5 5], [0 1]. Their fuzzy subsets are the same form {NB, NS, ZE, PS, PB}, the "tirmf" function is selected as the membership function.

4.2. Fuzzy Inference and Defuzzification

Mamdani minimum operator and Zadeh maximum and minimum method are adopted as the fuzzy inference. The center of gravity method is chosen as the solution of fuzzy decision to output a precise amount. The fuzzy rule is shown in Table 2.

$$x_0=\sum_{i=1}^{n} x_i u(x_i) \Big/ \sum_{i=1}^{n} u(x_i), \tag{9}$$

where x_i $(i = 1,2,3 \ldots\ldots n)$ is the element of the domain; x_0 is the average value, and $u(x_i)$ is the membership degree.

Table 2. Rule of fuzzy control.

EC	(E)				
	NB	NB	ZE	PS	PB
NB	NB	NB	NS	NS	ZE
NS	NB	NS	NS	ZE	PS
ZE	NS	NS	ZE	PS	PS
PS	NS	ZE	PS	PS	PB
PB	ZE	PS	PS	PB	PB

5. Simulation and Test Results

5.1. Simulation Result

The aircraft ABS single wheel simulation model is built in the MATLAB/Simulink environment. The simulation model is composed of fuzzy control model, servo valve model, brake model, runway and tyre model, fuzzy controller model, see Fig. 5.

This paper takes certain aircraft for example and plays attention to the diverse runway status during once landing is focused here. In the runway and tyre model, the runway surface condition is in turn set to dry, wet and ice, the time interval points are 6 s and 10 s.

Simulation conditions: the initial braking speed is 200 rad/s, the normal braking pressure is 8 MPa, the full load is 49 kN, the wheel moment of inertia is 3.77 kg.m^2 , the wheel rolling radius is 0.36 m. Fig. 6 shows the results of simulation.

The simulation results show that this system can accurately identify the runway status, real-time adjust the control parameters to maintain slip-rate in the vicinity of the desired value. Thus the friction force of runway is mostly used, and the braking efficiency is improved.

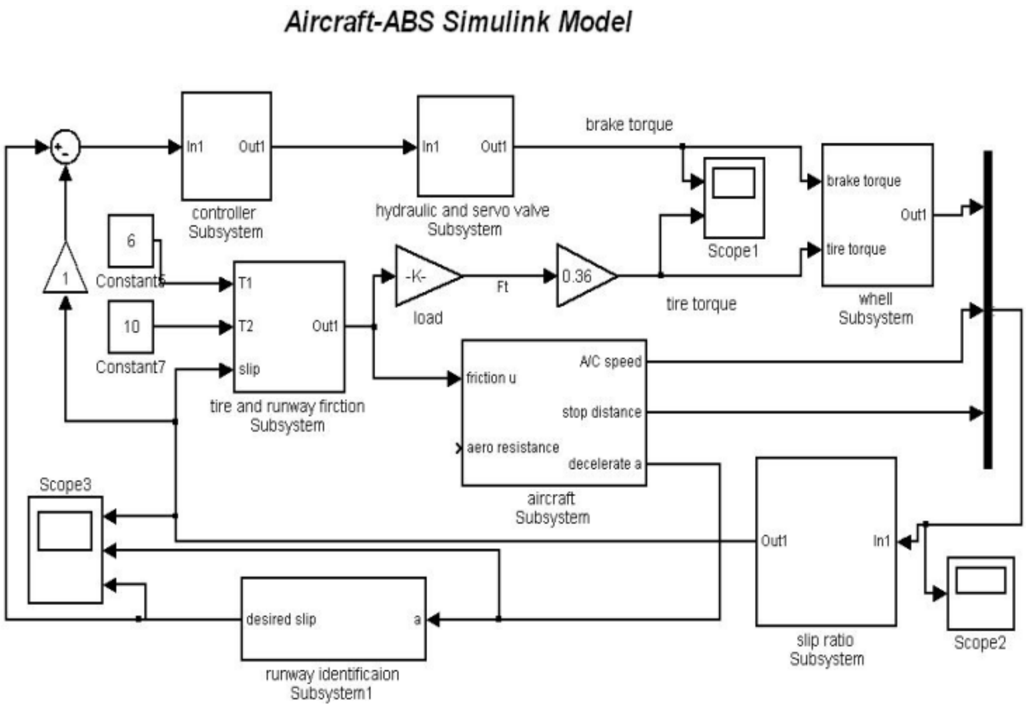
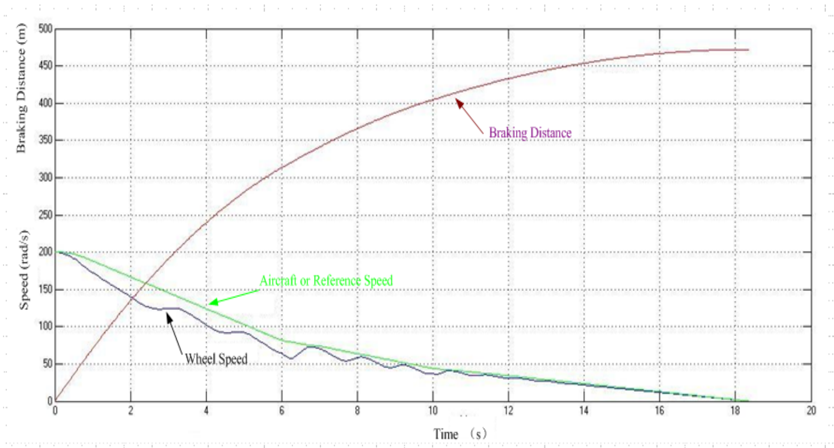
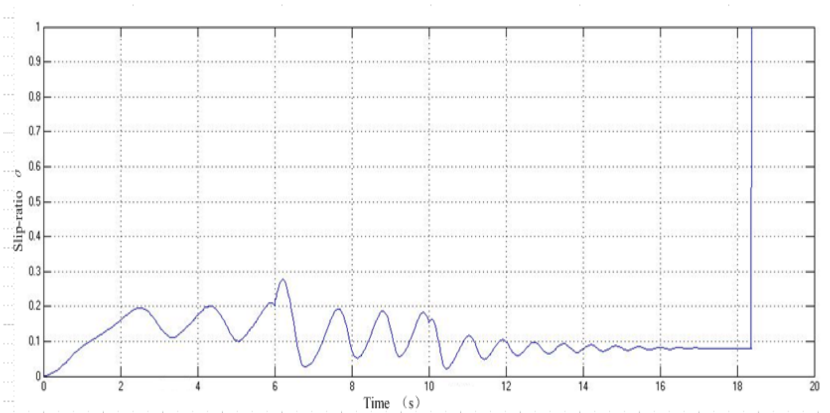


Fig. 5. Simulation model of the single wheel.



(a) Speed and distance vs. time.



(b) Slip vs. time.

Fig. 6. Simulation of Variable Runway Status (Dry: 0~6 s, Wet: 6~10 s, Ice: 10 s~).

5.2. Dynamic Test and Results

The inertial dynamic test (dynamometer test) is an important validation and performance evaluation of the aircraft ABS prior to delivery. The dynamometer tests such as full load (simulating the dry runway), 1/2 load (simulating the wet runway), 1/4 load (simulating the ice runway), are achieved In HJDS-II (a large inertial dynamic test platform in China). The test results are shown in Fig. 7. Test conditions: the initial braking speed of 240 km/ h, the braking pressure 8 MPa, full load 49 kN.

The dynamic test results show that, firstly, the braking process is smooth with high efficiency, the braking distance is short. Secondly, this system has strong adaptability to different runway surface conditions. Thirdly, the braking quickly achieves the desired state, the ground friction torque is fully utilized to improve the braking performance.

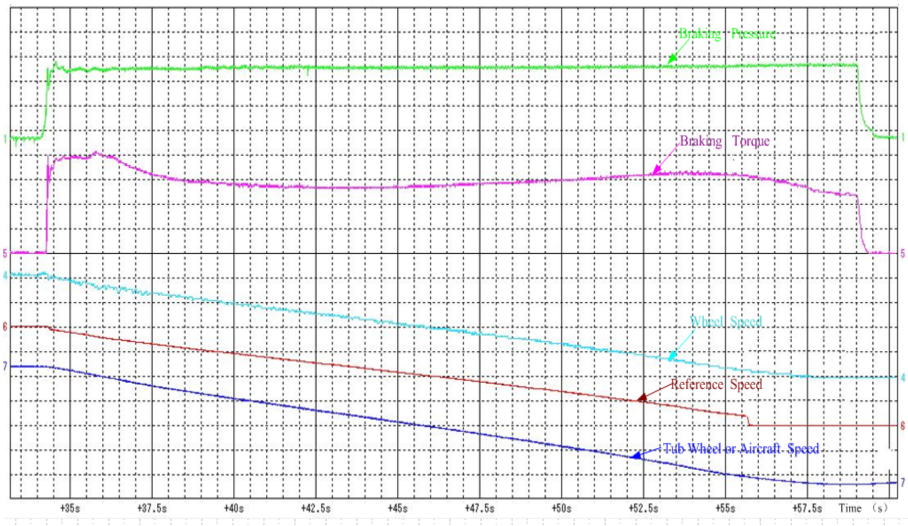


Fig. 7a. Full load dynamometer test.

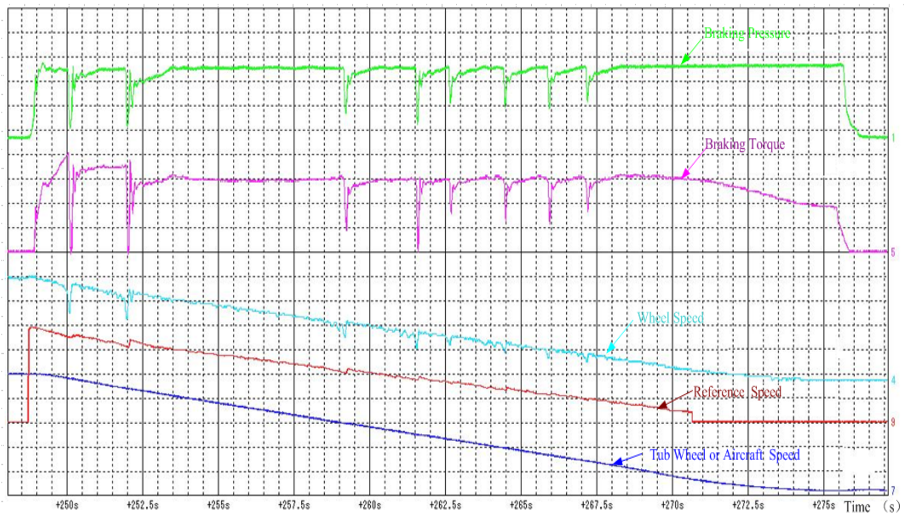


Fig. 7b. 1/2 Load dynamometer test.

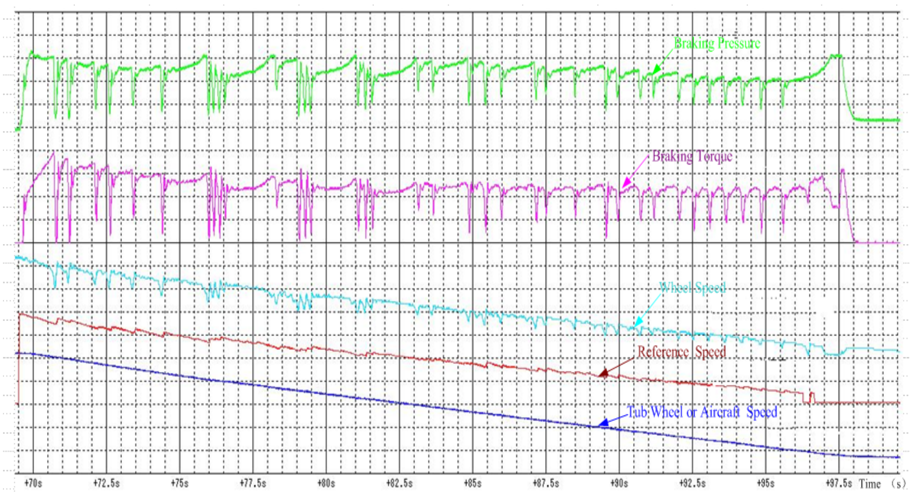


Fig. 7c. 1/4 Load dynamometer test.

6. Conclusion

A) The adaptive fuzzy control based on runway identification has higher accuracy and efficiency than the traditional anti-skid control, without additional hardware. The runway status is automatically recognized, the ideal slip-ratio of the runway is achieved in short time, the robustness and anti-jamming capability are enhanced, the performance is improved.
B) Because the un-precise mathematical model, it is convenient to develop the aircraft ABS in the integrated environments with the help of the fuzzy control and system simulation.
C) Multi-wheel, asymmetric landing and crosswind environment will be the focus of further research.

References

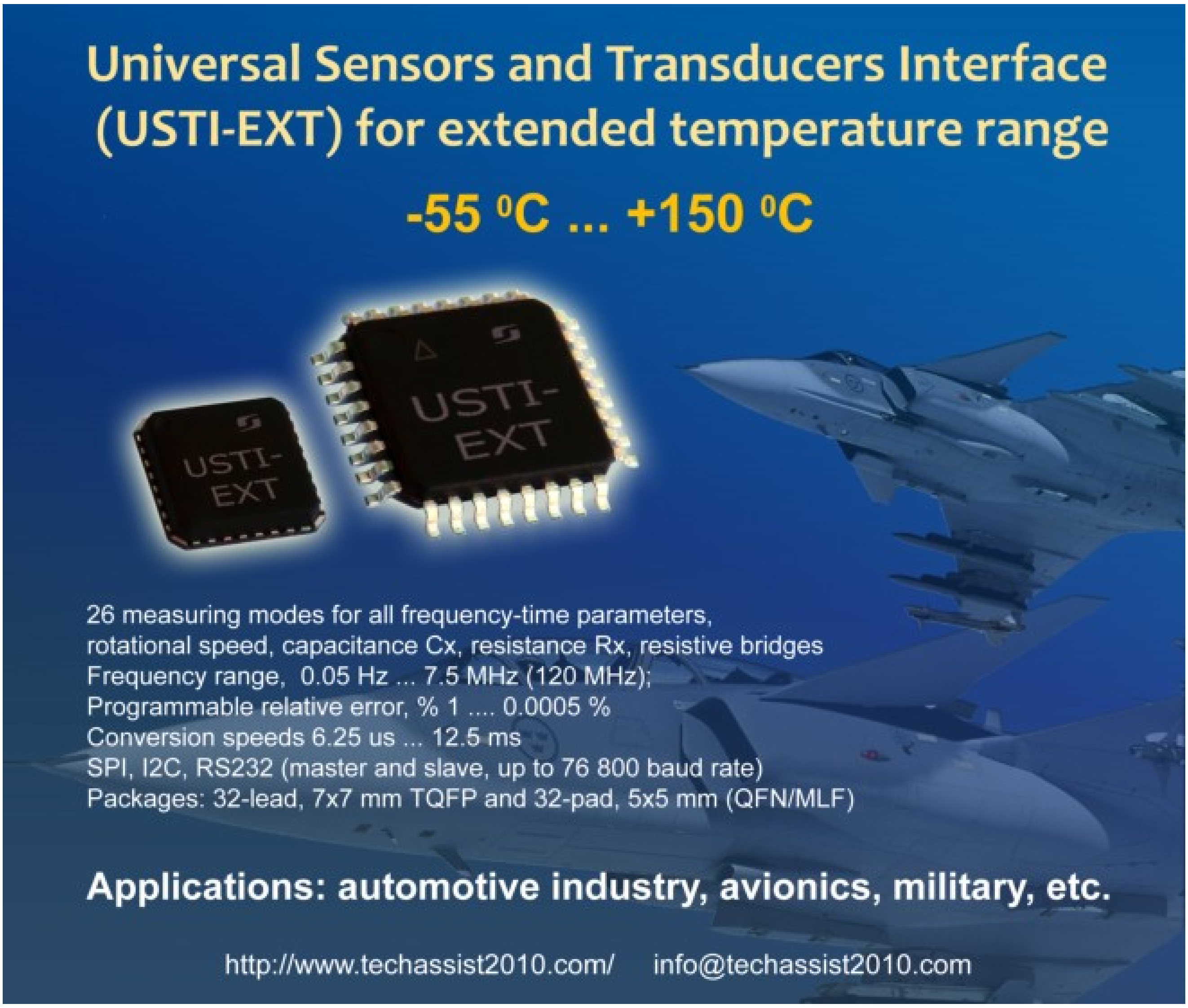
[1]. G. W. H. van Es, Running out of runway Analysis of 35 years of landing overrun accidents, *National Aerospace Laboratory,* USA, NLR-TP-2005-498, 2005.
[2]. Chang Shunhong, Tian Guanglai, Lin Hui, Application for Fuzzy Control in Aircraft Brake System, *Aviation Precision Manufacturing Technology*, Vol. 39, No. 6, 2003, pp. 33-36.
[3]. Chen Jinhua, Xie Li-i, Zou Meiying, Aircraft Anti-skid Braking System Behaviour's Improvement by Fuzzy Compound Control Law, *Computer Measurement & Control*, Vol. 14, No. 4, 2006, pp. 470-471, 512.
[4]. Yan Weiguang, Yu Datai, Li Guo, Wu Maosheng, Zhang Weidong, Fuzzy Adaptive Control Algorithm for Antilock Brake Systems, *Journal of Beijing University of Science and Technology*, Vol. 26, No. 2, 2004, pp. 188-191.
[5]. He Heng, Wu Ruixiang. Improved BP neural network in design of aircraft antiskid braking system, *Journal of Beijing University of Aeronautics et Astronautic*, Vol. 10, No. 6, 2004, pp. 561-564.
[6]. Ioan Ursu, Felicia Ursu, A Fuzzy Logic Control Synthesis for An Airplane Antilock-braking System, *Proceedings of the Romanian Academy*, Series A, 2004, pp. 1-10.
[7]. Duk-Hyun Park, Burbank, C.A., Optimal Control Design for Aircraft Antiskid Brake Control Systems*, US Patent* No. 0069902A1, 2004.
[8]. R. Somakumar, J. Chandrasekhar, Intelligent anti-skid brake controller using a neural network, *Control Engineering Practice,* No. 7, 1999, pp. 611-621.
[9]. *ATSB*, Investigation Report 199904538, Boeing 747-438, VH-OJH Bangkok, Thailand, 23 September 1999, (Year of Publication: 2001).
[10].Investigation Report 200202710, Runway Overrun at Darwin International Airport, *The Australian Transport Safety Bureau (ATSB),* 2004.
[11].FAA, AC 91-79, Runway Overrun Prevention, *U. S. Department of Transportation Federal Aviation Administration*, 2007.

[12]. H. B. Pacejka and R. S. Sharp, Shear Force Development by Pneumatic Tyres in Steady State Condition, *A Review of Modeling Aspecs. Vehicle Systems Dynamicss*, 20, 1991, pp. 121-176.

[13]. Wang Jisen, He Chang'an, Determination of Tyre-Runway Friction Coefficient, *Journal of Northwestern Polytechnic University*, Vol. 18, No. 4, 2000, pp. 569-571.

[14]. Zheng Wei, Qi Jie, Jiang Wei, Application of GP in Aircraft Runway Parameter Identification, *Computer Measurement & Control*, Vol. 15, No. 7, 2007, pp. 909-912.

[15]. Ilker Tunay, Antiskid Control for Aircraft via Extremum- Seeking, in *Proceedings of the American Control Conference,* Arlington, VA, June 25-27, 2001, pp. 665-670.



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